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Root System Characteristics of Two Soybean Isolines Undergoing Water Stress Condition

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ABSTRACT

Environmental stress may have a differential influence on root development of soybean [Glycine max (L.) Merr.] isolines which vary in pubescence density. Root length density and root dry matter distribution as a function of depth and distance from the row were determined for two isolines of 'Harosoy' soybean in association with an experiment designed to evaluate the influence of epidermal pubescence on root development, water use, and photosynthetic characteristics of the two isolines. The isolines, Harosoy normal (HN) and Harosoy dense (HD), differed in the density of trichomes on the epidermal surfaces of leaves, stems, and pods. The study was conducted at the Univ. of Nebraska Field Laboratory at Mead, Nebr., during the 1980 growing season. Root samples were collected 47 (full bloom) and 78 (beginning seed) days after planting. Until the first sampling, soil water content was high at all depths, and roots were concentrated in the surface 0.15-m layer, especially under the row. Eighty percent of the roots were found within the upper 0.30 m. By 78 days after planting and after 30 days of drought, root length density was greatest at the 0.90 to 1.20-m layer; 80% of the roots were found within the 0 to 1.2-m layer; and uniform lateral distribution was observed. Harosoy dense pubescence isoline tended to have a greater root density, to explore deeper into the soil, and to extract more soil water during the drought than did the normal pubescence isoline. However, the rate of water extraction (per unit root length) was greater for the HN isoline.

Additional index words: Glycine max (L.) Merr., Root length, Root weight, Root distribution, Water uptake rate.

SOYBEAN [Glycine max (L.) Merr.] root systems under field conditions at several stages of crop development have been described for different purposes. Raper and Barber (1970) studied the variation of root morphology as influenced by varietal and environmental factors.

Mitchell and Russell (1973) described the developmental phases and growth rates for eight soybean cultivars. They found that growth and development occurred in three phases. Downward tap and shallow horizontal lateral root growth accompanied top growth; root development to the 0.76-m depth accompanied flowering and pod formation, and deep penetration of several lateral roots occurred during seed maturity. They also observed that root dry weight was concentrated in the upper portions of the soil profile—90% or more in the upper 0.075 m early in the season, and in the upper 0.15 m during the remainder of the season. They also observed cultivar differences in root development.

The effect of irrigation on rooting pattern was evaluated by Mayaki et al. (1976) for the Williams variety. At physiological maturity, 67% of soybean root dry matter (DM) was in the 0 to 0.15-m layer and 80% in the 0 to 0.90-m layer of the irrigated soybean as compared to 51 and 83%, respectively, for the nonirrigated soybean.

Arya et al. (1975) examined soybean rooting characteristics and water extraction patterns to determine the interaction between rooting patterns and soil hydraulic properties as related to water uptake. Although rooting densities varied from 0.7 to 50.0 km/m^3 at maturity, the major portion of the root zone exhibited densities in the 10.0 to 20.0-km/m^3 range. They ob-

served an increasing rooting density with depth, until reaching a maximum concentration at 0.20 to 0.40-m depth, with a constant decreasing concentration below. Their data suggested that the difference in water potential between the root surface and the adjacent soil was directly proportional to sink strength, and inversely proportional to effective soil water conductivity and rooting density.

Allmaras et al. (1975) measured root length density (RLD) and water uptake by two isolines (determinate and indeterminate) of 'Harosoy' soybean in a Nicollet sandy clay loam, with frequent perched water table at 1.3 to 2.0 m. From 1 July to 15 August both soybean isolines had about 2.0 km/m^3 RLD in the Ap layer and less than 1.0 km/m^3 below this layer. Maximum soybean rooting depth coincided with maximum depth of water uptake. Water conductivity through the root systems for both soybean isolines had the same range and decreased linearly as soil water potential decreased. Maximum rooting depth was 1.20 m for both isolines.

Although considerable information on soybean root system is available, there is still need for in situ characterization of rooting patterns under a wide range of soil and environmental conditions. The study reported here was undertaken as a part of a research project on microclimate-plant architecture interaction effects on photosynthesis and water-use efficiency of the soybean crop. The objective of this report is to describe the changes which occurred in the rooting pattern of two soybean isolines during a midsummer drought, which was encountered during the course of conducting the major experiment.

MATERIALS AND METHODS

This study was conducted during the 1980 growing season at the Univ. of Nebraska Agricultural Meteorology Field Laboratory, Mead, Nebr. Root samples were taken from adjacent plot areas (approx. 140 m apart) planted with Harosoy normal pubescence (HN) and Harosoy dense pubescence (HD) isolines in 0.76-m wide north-south rows on a Sharpsburg silty clay loam (fine, montmorillonitic Typic Arqiudoll). The HD isoline possesses four times as many trichomes on the epidermal surfaces of leaves, stems, and pods and seems to have more vegetative vigor than the normal isoline (Singh et al., 1971).

Two sets of root samples were collected: the first, on 7 July (47 days after planting) when the crop was in full bloom (R2) (Fehr and Caviness, 1977) and the second on 8 August (78 days after planting) when the crop was at the beginning seed (R5) stage. A hydraulic coring machine was used to extract 76.2-mm-diam soil cores 0, 0.19, and 0.38 m from the planted row to a depth of 1.50 m. Cores were subsequently sectioned in 0.15-m increments. Samples were stored in a cold room (−20°C) for no more than 150 days until root separation. Within each plot area, root samples were replicated four times for the first, and three times for the second sampling. Data were analyzed as a nested design because the replications occurred only within the adjacent plot areas planted to the two isolines studied.

Roots were separated from soil using a modification of the washing technique described by Ward et al. (1978). Roots were separated from organic debris and stored in a 50% (V/V) ethanol-water solution until DM and length measurements were made.

Root length was estimated according to Newman's (1966) line intercept method modified by Tennant (1975). A plastic disk imprinted with a 20-mm-square grid was laid over the washed roots, which were uniformly distributed on a 150-mm-diam filter paper. Number of intersections between grid lines and roots were counted manually. Number of intersections were converted into RLD:

Root length density (RLD) = root length (km)/sample volume (m^3) = 15.714 × N/sample volume,

where N is the number of counts per sample (Tennant, 1975). After measuring root length, roots were dried at 80°C and weighed for DM.

Soil water content was determined by the neutron scatter method with a depth probe. Data reported represent the mean of three replications. Readings were taken periodically in 0.30-m increments to 1.50 m. Sites of soil water measurements were within 10 m of the root sample sites.

Additional information on meteorological conditions (Balbocchi, et al., 1983) and leaf area and DM production (Clawson[3]) can be found elsewhere.

RESULTS AND DISCUSSION

At the time of the 7 July root sampling, both HN and HD had attained a leaf area index (LAI) of 2.8 and were at full bloom (stage R2); their vegetative stages were 9.0 and 9.2, respectively. Soil water content had been high since planting time as indicated by the 16 June and 8 July soil water profiles shown in Fig. 1; 125 mm rainfall had fallen between planting and the 7 July sampling date.

When the second sampling was completed on 8 August, LAI values were 4.6 and 5.2 for HN and HD, respectively. The HD was at vegetative stage 17.6, while HN was at the 16.9 stage. Both isolines were at the same reproductive stage: R5.5 or beginning seed formation. Only 18 mm of rainfall was received during the 32-day period between root samplings, resulting in a steady decrease in soil water content, which reached the minimum value for the season at time of this sampling (Fig. 1).

Vertical distribution of roots was determined, both in terms of length density and DM, at the two sampling dates by averaging data from the three lateral sampling points across the row (0, 0.19, and 0.38 m from the row). Forty-seven days after planting, 80 and 70% of the roots (RLD) occurred in the upper 0.30 m (Table 1) for HN and HD, respectively. Likewise, about 80 and 70% of the roots, when expressed as DM, were found in the surface 0.15 m (Table 2), respectively. For both methods of measurements, virtually 100% of the roots occurred above the 0.60-m soil depth. Both isolines had similar root pattern distributions, characterized by a sharp decrease of root density with depth. This result is consistent with other soybean root studies (Mitchell and Russell, 1973; Mayaki et al., 1976).

At the second sampling (7 August) 32 days later, drastic changes in root development had occurred as measured by DM, volume of soil explored, and spatial distribution. Root DM doubled for HN and quadrupled for HD during these 32 days (Table 2), while RLD increased approximately threefold for HN and sevenfold for HD (Table 1). Rooting depth had exceeded 1.50 m for both isolines.

[3] Clawson, K.L. 1983. Physiological and agronomic responses of diverse pubescent soybean isolines to drought stress. Ph.D. Diss. Univ. Nebr.-Lincoln Library. (In press).

The vertical distribution pattern of RLD at the second sampling was characterized by an increase of roots in the 0.45 to 1.50-m layer (Table 1). The HD isoline had a dramatic increase, especially in the 1.05 to 1.20-m layer. Dry matter varied less with depth than did RLD because large roots in the upper layers contributed greatly to DM but not to root length. This root distribution pattern greatly departed from the linear or exponential decrease with depth generally found in root studies (Allmaras et al., 1975; Mayaki et al., 1976). Such a pattern of spatial distribution may be a consequence of the 30-day drought period between samplings which resulted in the upper 0.30 m of soil drying beyond the wilting point (Fig. 1). From the soil water profiles 7 days before and on the day of the sampling (profiles 29 July and 7 August in Fig. 1), it appeared that roots were extracting very little water from the 0 to 0.30-m layer which had an estimated water potential less than −2000 kPa. During this 32-day period, soil water extraction was occurring mostly from depths below 0.60 m, where estimated soil water potential was greater than −200 kPa.

The pattern of water extraction (Fig. 1) for both HD and HN matched the RLD pattern (Table 1). Soil water profiles 1 and 2 prior to the first root sampling and

profiles 3 and 4 prior to the second sampling illustrate this point.

In Table 3, horizontal distribution of roots, as measured by RLD at the two sampling dates, is presented. Values are percentages of the total roots measured in each soil layer. At the first sampling date, generally less than 20% of the roots were found midway between

Table 2. Root dry matter and standard deviation for Harosoy normal (HN) and Harosoy dense (HD) pubescence isolines, as affected by soil depth and sampling date.

	Sampling date			
	7 July		8 August	
Soil depth	HN	HD	HN	HD
m	g/m³			
0–0.15	137 ± 92	85 ± 25	44 ± 23	53 ± 19
0.15–0.30	22 ± 9	15 ± 5	30 ± 21	39 ± 24
0.30–0.45	4 ± 3	12 ± 8	24 ± 10	68 ± 46
0.45–0.60	2 ± 3	6 ± 3	26 ± 23	38 ± 10
0.60–0.75	3 ± 2	1 ± 1	79 ± 76	41 ± 3
0.75–0.90	2 ± 2	1 ± 1	36 ± 17	45 ± 12
0.90–1.05	--	--	32 ± 21	53 ± 6
1.05–1.20	--	--	24 ± 18	52 ± 9
1.20–1.35	--	--	16 ± 13	32 ± 3
1.35–1.50	--	--	11 ± 15	27 ± 8

Table 1. Root length density (RLD) and standard deviation for Harosoy normal (HN) and Harosoy dense (HD) pubescence isolines, as affected by soil depth and sampling date.

	Sampling date			
	7 July		8 August	
Soil depth	HN	HD	HN	HD
m	km/m³			
0–0.15	2.8 ± 0.5	2.4 ± 0.2	1.5 ± 0.5	2.1 ± 0.5
0.15–0.30	1.8 ± 0.5	1.0 ± 0.4	1.0 ± 0.2	1.4 ± 0.2
0.30–0.45	0.4 ± 0.2	0.8 ± 0.2	1.5 ± 0.9	1.7 ± 0.9
0.45–0.60	0.4 ± 0.0	0.4 ± 0.2	1.8 ± 0.5	3.1 ± 0.5
0.60–0.75	0.2 ± 0.2	0.1 --	2.0 ± 0.6	4.0 ± 0.6
0.75–0.90	0.2 ± 0.1	0.0 --	2.2 ± 1.2	4.9 ± 1.2
0.90–1.05	--	--	2.2 ± 1.5	4.7 ± 1.5
1.05–1.20	--	--	2.1 ± 1.6	6.4 ± 1.6
1.20–1.35	--	--	1.0 ± 0.9	2.9 ± 0.9
1.35–1.50	--	--	0.4 ± 0.4	2.7 ± 0.4

Table 3. Horizontal and vertical distribution of roots (measured as root length density (RLD) for Harosoy normal (HN) and Harosoy dense (HD) pubescence isolines at two sampling dates.

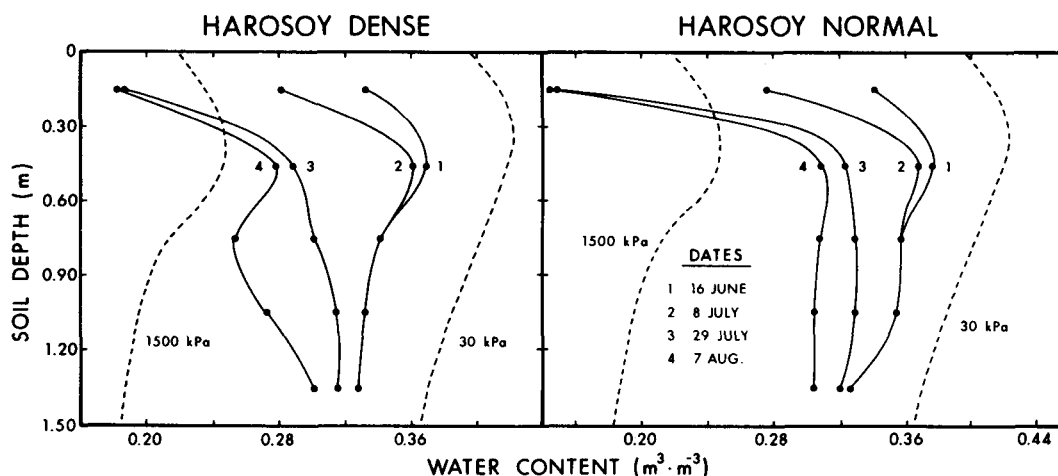| | HN | | | HD | | |
Soil depth	Row	¼ row	½ row	Row	¼ row	½ row
m	% of total RLD within each depth					
	7 July					
0–0.15	56	23	21	52	28	20
0.15–0.30	38	31	31	39	41	20
0.30–0.60	82	6	12	53	32	15
	8 August					
0–0.30	34	35	31	37	31	32
0.30–0.60	31	36	33	27	35	38
0.60–0.90	36	37	27	32	33	35
0.90–1.20	49	24	27	30	31	39
1.20–1.50	54	35	11	34	30	36

Fig. 1. Soil water profiles at selected dates for Harosoy dense and Harosoy normal isolines.
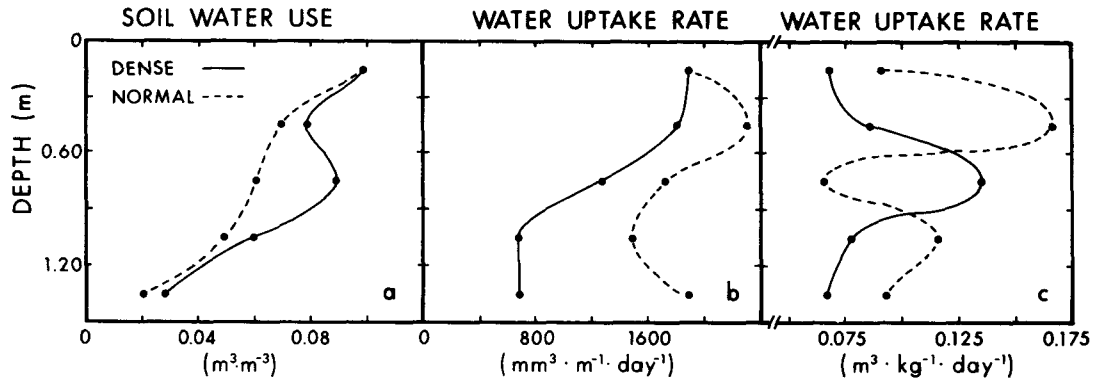
Fig. 2. Soil water use (a), and water uptake rate on a root-length (b) and dry-weight (c) basis for Harosoy dense and Harosoy normal pubescence isolines of soybeans.

Table 4. Horizontal and vertical distribution of roots (measured as dry matter) for Harosoy normal (HN) and Harosoy dense (HD) pubescence isolines at two sampling dates.

Soil depth	HN			HD		
	Row	¼ row	½ row	Row	¼ row	½ row
m	% of total DM within each depth					
			7 July			
0–0.15	83	13	4	77	14	9
0.15–0.30	45	28	27	43	40	17
0.30–0.60	66	16	18	52	20	28
			8 August			
0–0.30	50	26	24	42	34	24
0.30–0.60	46	23	31	47	21	32
0.60–0.90	60	21	19	23	43	34
0.90–1.20	50	22	29	30	30	40
1.20–1.50	31	41	28	38	29	33

rows. Except for the 0.15 to 0.30-m depth, over 50% of the roots were found directly beneath the row. At the later sampling date, generally 30 to 50% of RLD occurred under the row, with higher values at one-fourth and one-half row spacing than at the first sampling. The HD isoline tended to have greater RLD percentage at midrow than HN, especially at the deeper soil depths. When data are expressed in terms of root DM distribution (Table 4), the same conclusions can be made. By the last sampling date, relatively uniform horizontal root growth had occurred at all depths. Again, HN tended to have less root density at midrow than HD.

Total water use (Fig. 2a) and root density data (Table 1) were used to calculate rate of water uptake between the two sampling dates (Fig. 2b and 2c). Values in Fig. 2b and 2c were based on both RLD and DM, respectively.

Water uptake per unit root length (Fig. 2b) during the drought period for HD generally declined with depth in the soil. The HN isoline, although showing considerable variation with depth, had a greater rate of water uptake per unit root length at all depths than HD. Water uptake based on root DM (Fig. 2c) for HD tended to follow the general pattern of the soil water use curve (Fig. 2a) with maximum uptake occurring at the depth of greatest soil water use. The HN isoline uptake pattern based on root DM tended to amplify

the pattern displayed when uptake was based on RLD. Water uptake rates reported are within the range reported by Reicosky et al. (1972) and near the lower end of the range reported by Allmaras et al. (1975) and Willatt and Taylor (1978). Root densities were similar to those reported by Allmaras et al. (1975), but somewhat greater than those reported by Willatt and Taylor (1978). The lower rates of water uptake in the current study resulted from the greater tension with which soil water was held as the drought under study progressed.

Harosoy dense tended to use more soil water than HN. Although uptake rate per unit root length tended to be greater for HN than HD, HD was more effective in the total amount of soil water extracted, which is a critical survival mechanism during drought. The apparent difference in water uptake rates may have resulted from the greater difficulty associated with extraction of water at greater tensions or the greater length of root available to extract water, which would physically limit the quantity of water each unit of root could extract.

The data reported in this paper, together with the findings of Sivakumar et al. (1977) and Boyer et al. (1980) on root distribution, indicate that, under midsummer drought, the soybean root profile can be characterized by a low root density in the dry surface layer and a maximum root proliferation in the deeper, wetter soil layers. In general, roots appear to proliferate in those soil zones with lowest soil water tension.

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